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REPORT

NO. WAL 710/1048
D/A PROJECT NO.: 593-08-020
O. O. PROJECT NO.: TB4-10

BALLISTIC EVALUATION OF EXPERIMENTAL NYLON HELMET LINERS, T54-1 WITH AND WITHOUT M1 STEEL HELMET SHELLS

BY

F. S. MASCIANICA

DATE 11 October 1954

WATERTOWN ARSENAL
WATERTOWN, MASS.

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Authorized by:	ORDTB-Materials
D/A Project Number:	593-08-020
O.O. Project Number:	TB4-10
Report Number:	710/1048
D/A Priority:	1C
Title of O.O. Project:	Armor Materials
Filing Title:	Personnel Armor

TITLE

Ballistic Evaluation of Experimental Nylon Helmet Liners, T54-1 With and Without M1 Steel Helmet Shells

OBJECT

To evaluate comparative ballistic performances as follows:

a. Steel helmet shell, M1, fitted with nylon liner, T54-1, versus shell fitted with standard fibre liner, M1.

b. Nylon liner, T54-1, versus standard fibre liner, M1, both without helmet shells.

c. Steel helmet shell, M1, fitted with nylon liner T54-1, versus experimental EX-51-1 helmet (aluminum alloy shell with bonded nylon liner).

SUMMARY

Six experimental nylon helmet liners T54-1 which were submitted by the Quartermaster Research and Development Command of Natick, Massachusetts, on 9 September 1954 were subjected to ballistic evaluation. Protection ballistic limits (V50) were determined with the 9.85, 17 and 44-grain fragment-simulating projectiles at 0° obliquity for the experimental nylon helmet liners with and without the M1 steel helmet shells. The ballistic performance for these test conditions is compared to that of the standard M1 steel helmet shell with the present plastic fibre liner and EX-51-1 helmet with nylon liner, which had been evaluated by this Arsenal in previous tests.

CONCLUSIONS

1. Based upon ballistic tests with fragment-simulating projectiles at 0° obliquity, the protection performance of the steel M1 helmet shell fitted with the experimental nylon helmet liner, T54-1, is as follows:

a. It is significantly superior to the steel M1 helmet shell fitted with the standard fibre liner against fragments of all weights (5.85 to 44 grains) even though both types of helmets are of approximately the same weight.

b. It offers somewhat more protection than the EX-51-1 helmet (aluminum shell plus laminated nylon liner) against light weight (5.85-grain) missiles, but offers somewhat less protection against heavier missiles (17 to 44 grains).

2. Even though both helmet liners (bonded nylon, T54-1 and M1 fibre) are of approximately the same weight, the experimental T54-1 liner offers a marked improvement in the ballistic protection against simulated fragments as compared to the M1 plastic fibre liner.

3. Since the experimental nylon helmet liner, T54-1, fits into the standard steel M1 helmet shell, this liner can be substituted for the present standard fibre liner and achieve a great increase in protection.

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INTRODUCTION

The Personnel Armor Program of the Ordnance Corps includes the investigation and development of steel and non-ferrous alloys, plastics, plastic laminates and combinations of these materials suitable for use in personnel armor (helmets, armored garments, eye protectors, etc.) of superior ballistic protection so as to provide American troops with as much protection as possible for a given weight against small shell fragments and other low velocity missiles. This development work on helmets and helmet liners has been conducted along the lines of providing an improved design by making use of improved armor materials. This has advanced to the point where many experimental headpieces[1,2,3] were developed and ballistically tested with various missiles. In a recent report,[3] it was recommended by this Arsenal that the present fibre liner of the M1 helmet be replaced by a bonded nylon liner of approximately equal weight, since the ballistic protection afforded by the standard M1 fibre liner against missiles is almost negligible.

The Quartermaster Corps contracted with Victory Plastics Company of Hudson, Massachusetts to develop a bonded nylon helmet liner made of plasticized and laminated nylon duck, the design being referred to as T54-1. This liner was to have the same approximate weight and same geometric design as the fibre liner in the present M1 helmet, since the experimental liner was to be used in combination with the standard M1 steel helmet shell.

The results of the ballistic tests which were conducted on these experimental helmet liners T54-1 have been forwarded to the Office, Chief of Ordnance, and to the Quartermaster Corps in letter file ORDBE-L 423/410C, Subject: Ballistic Tests of Experimental Nylon Helmet Liners, T54-1, With and Without M1 Steel Helmet Shells, dated 12 October 1954.

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1. Watertown Arsenal Laboratory Report No. WAL 710/998(c) - PERSONNEL ARMOR - "Ballistic Evaluation of Laminated Nylon Helmet Liner, Model EX-49-3" dated 28 January 1952.
2. Watertown Arsenal Laboratory Report No. WAL 710/999(c) - PERSONNEL ARMOR - "Ballistic Evaluation of Aluminum Alloy Helmet Shells and Laminated Nylon Liners, Model EX-49-3" dated 11 February 1952.
3. Watertown Arsenal Laboratory Report No. WAL 710/1013(c) - PERSONNEL ARMOR - "Ballistic Evaluation of M1 and Experimental EX-51-1 Helmets" dated 21 August 1953.

MATERIALS

T54-1, Bonded Nylon, Helmet Liner

The six liners of one size weighed 10.2 ounces (average of six liners) without chin strap and suspension components. The liners were molded from four layers of 2 x 2 basketweave nylon duck weighing 13.5 ounces per square yard per ply. The nylon duck was procured under Military Specification MIL-C-12369 (QMC) entitled "Cloth, Nylon Duck, Lightweight." The nylon fabric was bonded with thermosetting, phenolic butyral resin in which approximately 90% of the total weight of the liner is nylon duck and approximately 10% is resin (Permacel 1500 or equal). The helmet shape is similar to that of the present M1 fibre liner. The T54-1 liner was painted on the outside with an olive drab paint, OD7.

For each T54-1 liner, the minimum, maximum and average thickness readings (based on one hundred measurements) are presented as follows:

Liner Number	Thickness (Inches)		
	Minimum	Maximum	Average
3	0.076	0.102	0.090
6	0.078	0.096	0.088
7	0.081	0.100	0.090
8	0.073	0.119	0.093
10	0.071	0.113	0.092
11	0.078	0.123	0.095

The average thickness of the six liners, T54-1 in the impacted areas is 0.090".

M1, Steel Helmet with Fibre Liner

The steel shell of the helmet, M1 is made according to Military Specification MIL-H-10990 (QMC) dated 5 March 1951 entitled Helmet, Steel M1, and Quartermaster Corps Helmet, Steel, M1; Assembly and Detail Drawing Nos. 2-1-87, 2-1-88 and 2-1-93. The steel helmet shells were fabricated from Hadfield-manganese steel by cold stamping operations. A detailed description of these operations, dimensional tolerances and chemistry of the steel shell and the make-up of the fibre liner is described in previous Watertown Arsenal reports[3,4]. For each steel helmet shell the minimum, maximum and average thickness readings (based on one hundred measurements) are presented as follows:

---

4. Watertown Arsenal Laboratory Report No. WAL 710/776(c) - "Helmets - Metallurgical and Ballistic Comparison of German, Japanese and American (M1) Helmets" dated 21 September 1945.

Steel Helmet Shell	Thickness (Inches)		
	Minimum	Maximum	Average
6	0.036	0.047	0.042
7	0.037	0.047	0.041
11	0.038	0.047	0.042

The average thickness of the three helmet shells, M1, in the impacted areas is 0.044".

TEST PROCEDURE

Bands of one-inch square grids having a total width of four inches were marked off on the outer surfaces of the headpieces from front to back and from side to side as shown in photographs 1 to 6. Thickness measurements were taken at the midpoints of all squares in the grid network by means of a dial micrometer which was mounted on a special fixture.

The T54-1 liner when tested singly or in combination with the helmet shell was rigidly clamped around the rim using an adjustable fixture which could be moved up and down and side to side during the course of the ballistic tests. The target was positioned so that each round of ammunition would impact at the midpoint of the squares which had been previously marked off. The headpieces were positioned so that each round would strike the target normal to the impacted surface. Caliber .15, .22 and .30 fragment-simulating projectiles weighing 5.85, 17 and 44 grains respectively were employed in the ballistic evaluation. The projectiles were all heat treated to a hardness of Rockwell "C" 29-31 which is the typical hardness range of representative steel shell fragments from recovered American HE ammunition.

The gun to target distance was 10 feet and the test set-up employed was as follows: The first velocity measuring screen was placed 5 feet from the muzzle of the gun; the second velocity measuring screen was $2\frac{1}{3}$ feet away from the first velocity measuring screen and the target was $2\frac{1}{2}$ feet from the second velocity measuring screen. The instrument velocities of the projectiles were measured at a distance of 3 feet 9 inches in front of the target by means of a 400 kilocycle Potter Counter-chronograph triggered by breaking of circuits as the projectiles passed through very thin paper screens on which circuits were printed. All instrument velocities were converted to striking velocities[5] from which ballistic limits were computed.

5. Curves for converting "instrument" velocity to "striking" velocity for various fragment-simulating projectiles are presented in Watertown Arsenal Laboratory Report No. WAL 760/503 entitled, "Determination of Coefficient of Drag (K_D) and Development of Velocity Loss Equations for the Fragment-Simulating Type Projectiles Used to Evaluate Personnel Armor Materials," dated 27 January 1953.

The method employed in the computation of the protection ballistic limit (V50) is found in Appendix A. A complete penetration under the protection ballistic criterion is defined as one in which a fragment of either the armor or the projectile perforates a witness plate consisting of a 0.020" thick flat sheet of 24S-T4 aluminum alloy sheet placed 2" behind the target.

DATA AND DISCUSSIONS

Detailed tabulations of the ballistic tests conducted on nylon helmet liners T54-1 with and without the M1 steel helmet shells and computation of their ballistic limits are presented in Appendix A. A summary of these ballistic results showing the protection ballistic limits (V50), highest striking velocities resulting in partial penetrations, and lowest velocities resulting in complete penetrations is given in Table I. These ballistic characteristics are compared to the M1 helmet complete with the standard fibre liner, and the EX-51-1 helmet with nylon liner.

The ballistic results in Table I indicate that the M1 helmet in combination with the nylon liner, T54-1 having a total weight of 47.1 ounces (without suspension components) offers considerably higher resistance to penetration by all size fragment-simulating projectiles when compared to the steel M1 helmet in combination with its standard plastic impregnated fibre liner weighing 47.0 ounces with suspension. Against the 5.85, 17, and 44-grain missiles, the M1 helmet in combination with the nylon liner, T54-1 had protection ballistic limits (V50) of 2072, 1331 and 1052 feet per second respectively as compared to 1571, 1051 and 809 feet per second respectively for the M1 helmet complete with the standard fibre liner. The nylon liner, T54-1, having the same approximate weight as the present standard M1 plastic impregnated fibre liner, when used in combination with the steel M1 shell markedly improves the ballistic properties of the M1 helmet.

The present standard M1 plastic fibre liner which weighs 10.1 ounces with suspension offers little ballistic protection against missiles. At 0° obliquity, against the caliber .22 fl37 (17-grain) projectile the standard M1 fibre liner had a protection ballistic limit (V50) of 343 feet per second as compared to 818 feet per second for the nylon liner, T54-1 which weighs 10.2 ounces. Against the 5.85 and 44-grain projectiles, the nylon liner, T54-1, had protection ballistic limits (V50) of 992 and 706 feet per second respectively. Since the standard M1 fibre liner afforded so little protection against the 17-grain projectile, it was not feasible to fire other missiles because of the very low velocities required for testing this component.

The small and large size EX-51-1 aluminum alloy helmets in combination with their nylon liners weighing 43.1 and 47.5 ounces respectively

offer higher resistance to penetration by 17 and 44-grain missiles when compared to the steel M1 helmet in combination with the nylon liner, T54-1 weighing 47.1 ounces. Against the 17 and 44-grain projectiles, the EX-51-1 helmet with nylon liner had protection ballistic limits (V50) of 1411 and 1180 feet per second as compared to 1331 and 1052 feet per second for the steel M1 helmet in combination with the nylon liner, T54-1. However, against the small 5.85-grain projectile, the steel M1 helmet in combination with the nylon liner, T54-1, had a ballistic limit of 2072 feet per second as compared to 1913 feet per second for the EX-51-1 helmet with nylon liner. The Hadfield-manganese steel of the M1 helmet deforms the small missile, thereby spreading its force over a larger area which results in the improvement in the ballistic efficiency of the M1 helmet shell over that of the aluminum alloy shell, EX-51-1.

GENERAL CONSIDERATIONS

The tests show that at 0° obliquity the ballistic performance of the M1 steel helmet shell when fitted with the experimental bonded nylon liner, T54-1, provides significantly greater protection than the current standard M1 helmets in which a bonded fibre liner is employed. The steel M1 helmet fitted with the nylon liner provides somewhat greater ballistic protection than the EX-51-1 helmet (aluminum alloy shell and bonded nylon liner) against the light weight (5.85-grain) fragment-simulating projectiles but somewhat less protection against moderate to heavy weight (17 to 44-grain) fragment-simulating projectiles. Although ballistic tests of the nylon liner, T54-1, tested above and in combination with the M1 steel helmet shell have been limited to 0° obliquity and normal conditions of temperature and humidity, previous experience with the bonded nylon has shown that the marked ballistic superiority of the nylon liner over the present fibre liner would exist under other important test conditions.

In view of the marked superiority of the helmet combination incorporating the 10-ounce bonded nylon liner with the M1 helmet shell over the present M1 helmet incorporating a bonded fibre liner, it is considered desirable to replace the present standard fibre liners with the bonded nylon liners of the type (T54-1) evaluated in this report for all M1 helmets in service and supply.

Adoption of the M1 helmet shell fitted with the laminated nylon liner is considered feasible and desirable for the following reasons:

a. This combination represents a significant improvement in ballistic protection as compared to the present standard M1 helmet fitted with fibre liner.

b. The change in the helmet will permit the continued use of the standard M1 steel helmet shell, of which large quantities of recent manufacture are still available. The cost of the proposed modification will be modest in view of the great returns in increased performance.

c. Both the bonded nylon liner, T54-1 and the standard fibre liner, M1 have approximately the same weight.

d. Since the outer shell is unchanged, and the nylon liner closely resembles the present standard fibre liner, the appearance of troops wearing helmet liners or complete helmets remains unchanged.

e. Troops wearing the experimental T54-1 nylon liner alone are still provided with a respectable degree of protection from fragment type missiles, whereas the present standard fibre liner is worthless for this purpose.

Since it is recognized that complete acceptability of the bonded nylon liner to replace the present fibre liner depends upon other considerations such as durability, availability of material and processing equipment, cost, and serviceability other than ballistic performance, the nonballistic aspects should be evaluated prior to making a decision regarding adoption of this nylon liner which provides superior ballistic performance to the current standard liner.

TABLE I

COMPARATIVE BALLISTIC RESISTANCE OF M1 HELMET WITH FIBRE LINER, M1 HELMET WITH NYLON LINER, T54-1, EX-51-1 HELMET WITH LINER, AND NYLON LINER T54-1, WHEN ATTACKED BY FRAGMENT-SIMULATING PROJECTILES AT 0° OBLIQUITY

Type Helmet	Total Weight (ounces)	Projectile Caliber	Projectile Weight (grains)	Protection Ballistic Limit (V50) Ft/Sec	Striking Velocities Ft/Sec Resulting in Highest Partial Penetration	Striking Velocities Ft/Sec Resulting in Lowest Complete Penetration
M1 Helmet with Fibre Liner	47.0	.15	5.85	1571*	1732	1384
M1 Helmet with T54-1 Nylon Liner	47.1	.15	5.85	2072	2076	2062
EX-51-1 Helmet with Nylon Liner	43.1(Small) 47.5(Large)	.15 .15	5.85	1913*	1965	1829
T54-1 Nylon Liner	10.2	.15	5.85	992	1036	978
M1 Helmet with Fibre Liner	47.0	.22	17.0	1051*	1094	1016
M1 Helmet with T54-1 Nylon Liner	47.1	.22	17.0	1331	1368	1319
EX-51-1 Helmet with Nylon Liner	43.1(Small) 47.5(Large)	.22	17.0	1411*	1485	1275
T54-1 Nylon Liner	10.2	.22	17.0	818	850	786
M1 Fibre Liner	10.1	.22	17.0	343*	341	346
M1 Helmet with Fibre Liner	47.0	.30	44.0	809*	845	786
M1 Helmet with T54-1 Nylon Liner	47.1	.30	44.0	1052	1052	1027
EX-51-1 Helmet with Nylon Liner	43.1(Small) 47.5(Large)	.30	44.0	1180*	1214	1140
T54-1 Nylon Liner	10.2	.30	44.0	706	733	698

(Continued)

TABLE I (CONT)

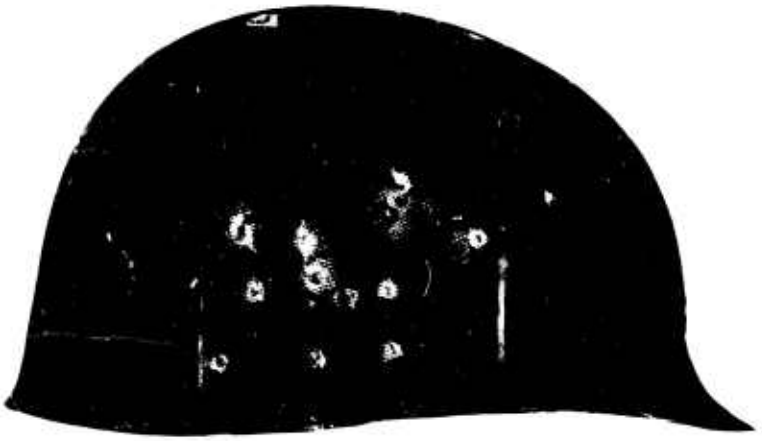
*Obtained from Watertown Arsenal Laboratory Report No. WAL 710/1013, "Ballistic Evaluation of M1 and Experimental EX-51-1 Helmets," dated 21 August 1953.

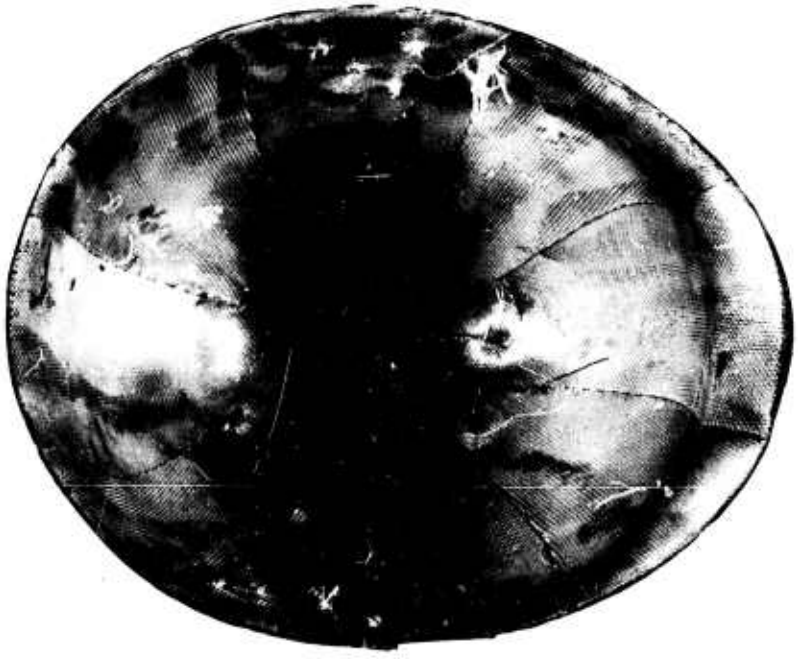
NOTES:-

1. The M1 steel helmet shell weighs 36.9 ounces and the standard fibre liner weighs 10.1 ounces

2. The small and large bonded nylon liners employed in the EX-51-1 helmet weigh 22.0 and 24.1 ounces respectively.

3. The small and large aluminum alloy EX-51-1 helmet shells weigh 21.1 and 23.4 ounces respectively.





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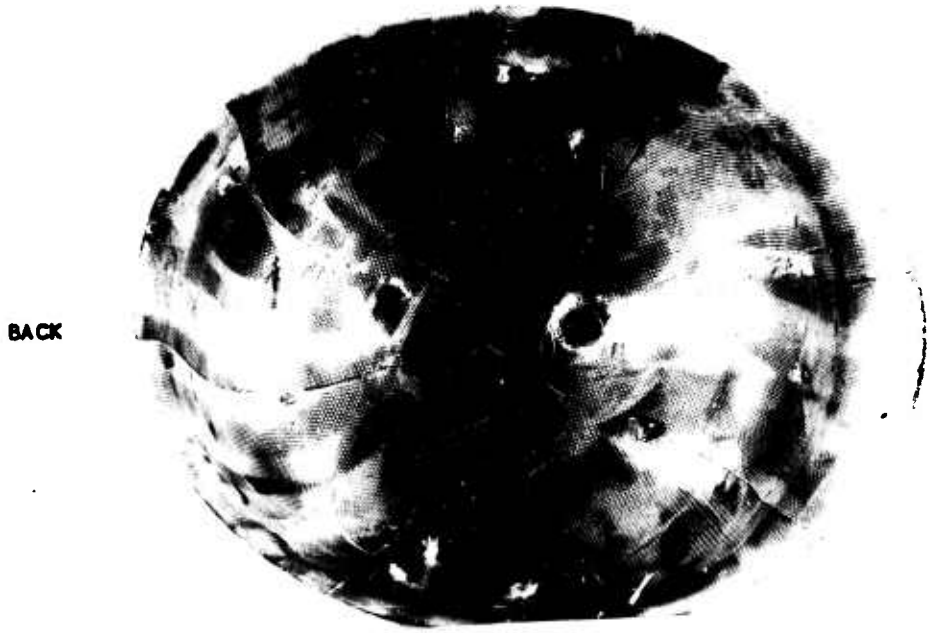
NYLON HELMET LINER, T54-1 AFTER BALLISTIC TESTING
WITH CALIBER .15 (5.85-GRAIN) PROJECTILES AT 0° OBLIQUITY

WTN 710-3350

FIGURE 1

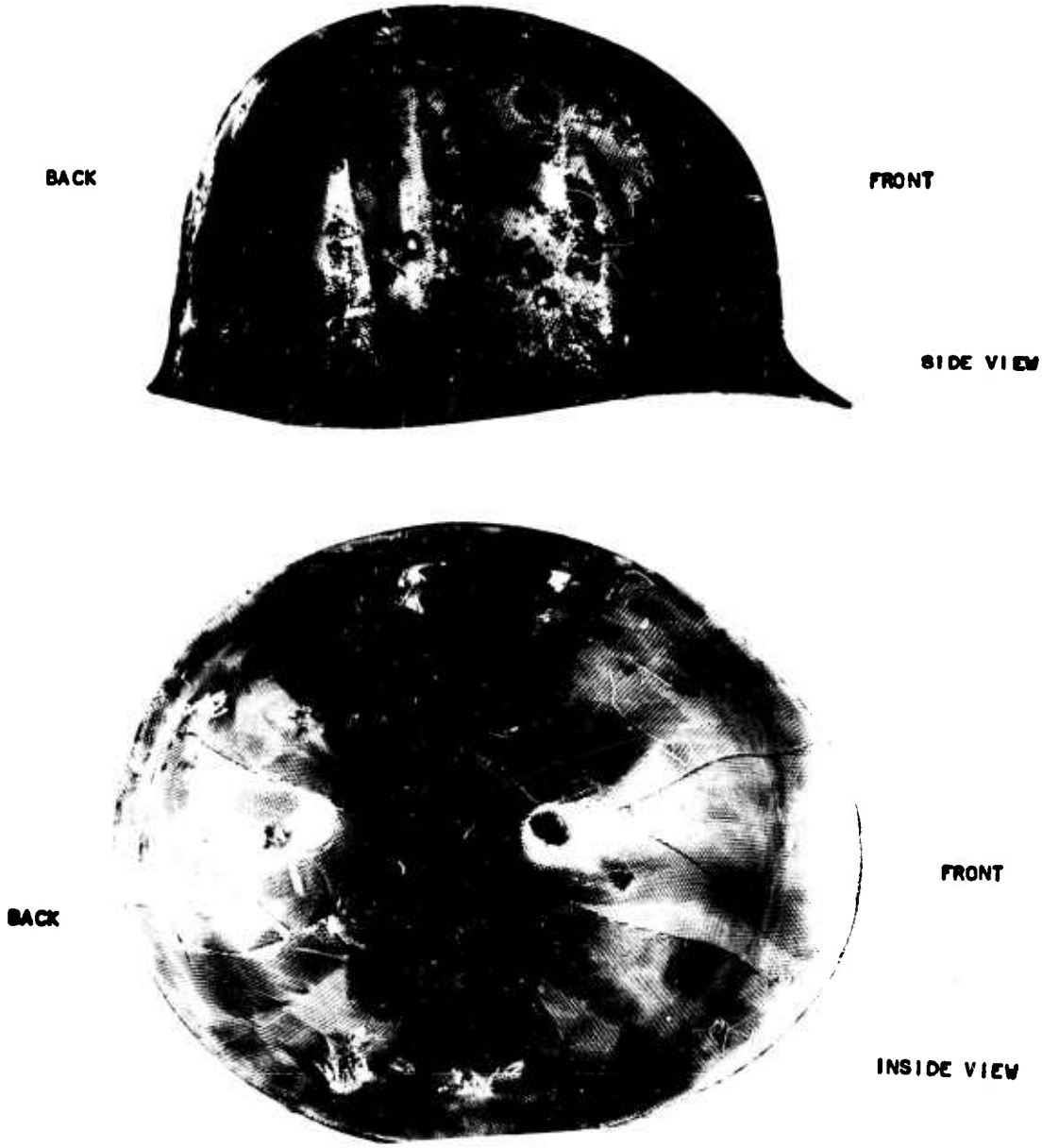


WATERTOWN ARSENAL LABORATORY

NYLON HELMET LINER, T54-1 AFTER BALLISTIC TESTING
WITH CALIBER .22 T37 (17-GRAIN) PROJECTILES AT 0° OBLIQUITY

WTN 710-3351

FIGURE 2



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NYLON HELMET LINER, T54-1 AFTER BALLISTIC TESTING
WITH CALIBER .30 (44-GRAIN) PROJECTILES AT 0° OBLIQUITY

WTN 710-3352

FIGURE 3

BACK

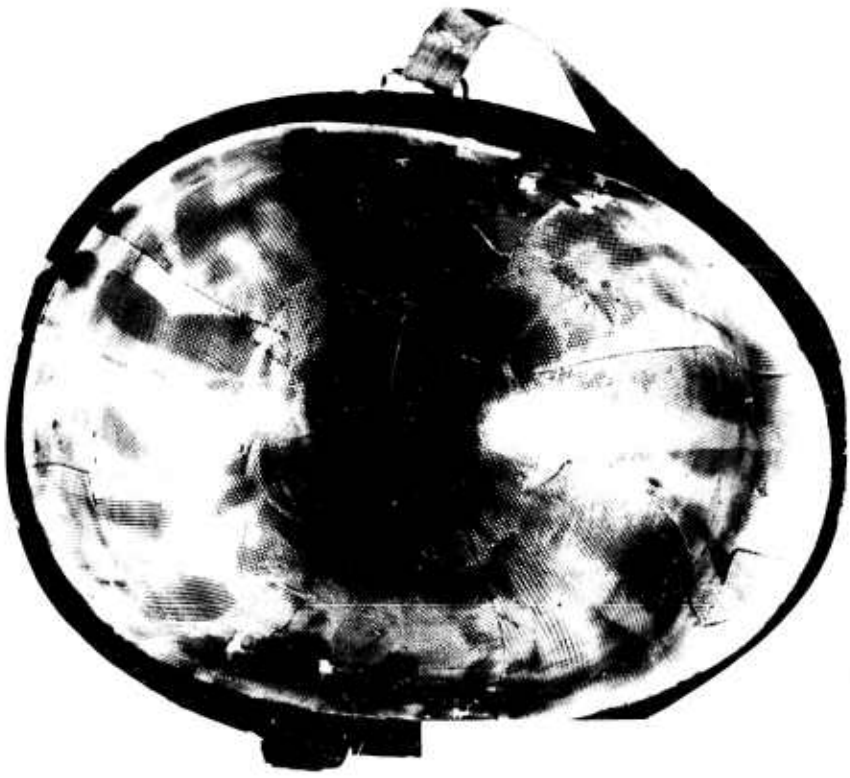
FRONT

SIDE VIEW

BACK

FRONT

INSIDE VIEW



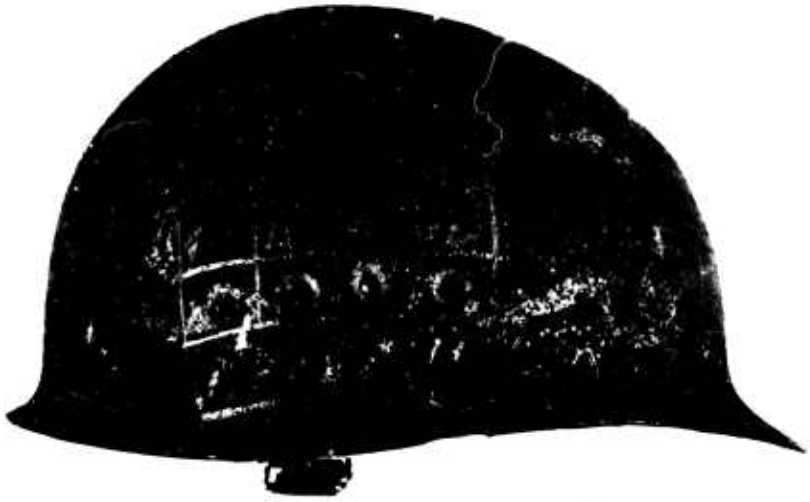
WATERTOWN ARSENAL LABORATORY

HELMET STEEL MI, WITH NYLON LINER T54-1 AFTER BALLISTIC TESTING WITH CALIBER .L5 (5.85-GRAIN) PROJECTILES AT 0° OBLIQUITY

WTN 710-3348

FIGURE 4

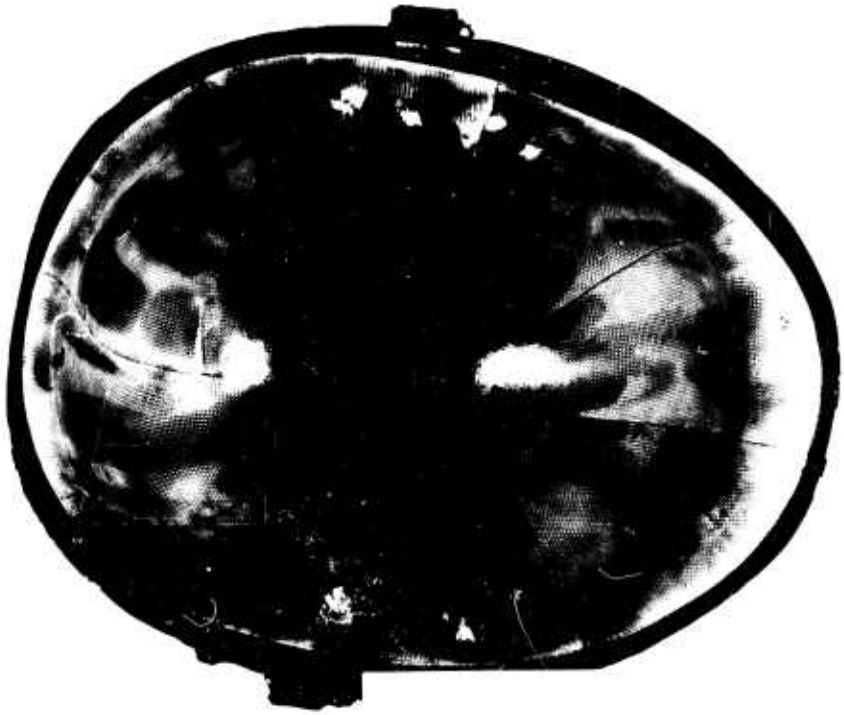
BACK



FRONT

SIDE VIEW

BACK



FRONT

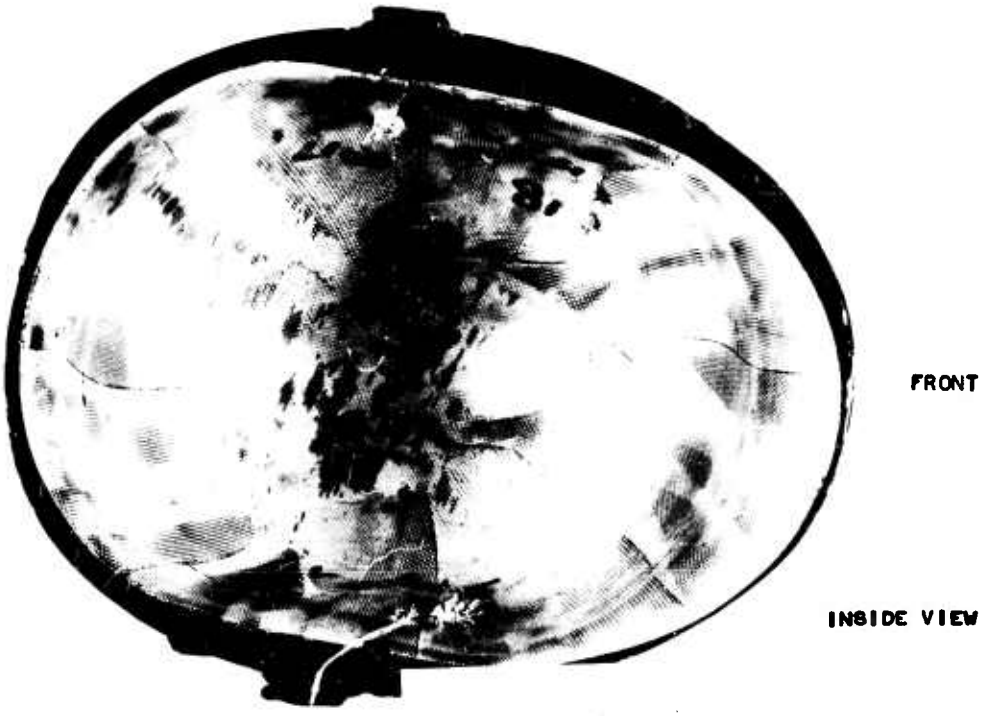
INSIDE VIEW

WATERTOWN ARSENAL LABORATORY

HELMET STEEL MI, WITH NYLON LINER T54-1 AFTER BALLISTIC TESTING WITH CALIBER .22 (17-GRAIN) PROJECTILES AT 0° OBLIQUITY

WTN 710-3349

FIGURE 5



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HELMET, STEEL M-1, WITH NYLON LINER T54-1 AFTER BALLISTIC TESTING WITH CALIBER .30 (44-GRAIN) PROJECTILES AT 0° OBLIQUITY

WTN 710-3353

FIGURE 6

APPENDIX A

Method for Obtaining Protection Ballistic Limit (V50) and Tabulation of Ballistic Test Data

Computation of Ballistic Limits

Protection ballistic limits (V50) were calculated from the average of ten fair-impact velocities which comprised the five lowest velocities that resulted in complete penetrations and the five highest velocities that resulted in partial penetrations. A maximum spread of 125 feet per second between the lowest complete and highest partial velocity was employed in the computation of the ballistic limit. In cases where the spread between the lowest complete and highest partial velocities was greater than 125 feet per second, the ballistic limit was based upon fourteen velocities, seven of which resulted in lowest complete penetrations and seven which resulted in the highest partial penetrations.

Ballistic Test Data of Combination Helmet, Steel M1 and Nylon Liner, Helmet Steel T54-1

Striking Velocities Ft/Sec Resulting In	
Partial Penetrations	Complete Penetrations
2076 Highest Partial	2062) Lowest Complete
2062	2062)
2052	2071
2037	2129
2033	2134
1994	2178
1907	
1718	
1519	

Obliquity - 0°
Projectile Type - Caliber .15 (5.85-grain) fragment-simulating. Hardness, Rockwell "C" 29-31.
Protection Ballistic Limit (V50) - 2072 Ft/Sec.
Average Thickness of Liner T54-1 - 0.090"

Ballistic Test Data of Combination Helmet, Steel M1 and Nylon Liner, Helmet Steel T54-1

Striking Velocities Ft/Sec Resulting In	
Partial Penetrations	Complete Penetrations
1368 Highest Partial	1319 Lowest Complete
1333	1323
1319	1333
1319	1333
1309	1353
1304	1363
1304	1377
	1387
	1407

Obliquity - 0°
Projectile Type - Caliber .22T37 (17-grain) fragment-simulating. Hardness, Rockwell "C" 29-31.
Protection Ballistic Limit (V50) - 1331 Ft/Sec.
Average Thickness of Liner T54-1 - 0.088"
Average Thickness of Steel Helmet Shell, M1 - 0.041"

Ballistic Test Data of Combination Helmet, Steel M1 and Nylon Liner, Helmet Steel T54-1

Striking Velocities Ft/Sec Resulting In Partial Penetrations	Striking Velocities Ft/Sec Resulting In Complete Penetrations
1052 Highest Partial	1027 Lowest Complete
1047	1032
1027	1091
1017	1096
1008	1121
978	
968	
963	
953	
944	
934	
767	

Obliquity - 0°
Projectile Type - Caliber .30 (44-grain) fragment-simulating. Hardness, Rockwell "C" 29-31.
Protection Ballistic Limit (V50) - 1052 Ft/Sec.
Average Thickness of Liner, T54-1 - 0.099"
Average Thickness of Steel Helmet Shell, M1 - 0.042"

Ballistic Test Data of Nylon Liner, Helmet Steel T54-1

Striking Velocities Ft/Sec Resulting In Partial Penetrations		Striking Velocities Ft/Sec Resulting In Complete Penetrations	
1036	Highest Partial	978	Lowest Complete
973		982	
973		1021	
948		1031	
939		1036	
905		1045	
905		1050	
900		1055	
900		1084	
895		1103	
889		1132	
886		1229	
87[illegible]		1365	
8[illegible]		1471	
857		1684	
847			

Obliquity - 0°
Projectile Type - Caliber .15 (5.85-grain) fragment-simulating. Hardness, Rockwell "C" 29-31.
Protection Ballistic Limit (V50) - 992 Ft/Sec.
Average Thickness of Liner, T54-1 - 0.095"
Minimum Thickness of Liner, T54-1 - 0.078"
Maximum Thickness of Liner, T54-1 - 0.123"

Ballistic Test Data of Nylon Liner, Helmet Steel T54-1

Striking Velocities Ft/Sec Resulting In Partial Penetrations	Striking Velocities Ft/Sec Resulting In Complete Penetrations
850 Highest Partial	786 Lowest Complete
840	811
830	816
801	825
791	830
752	840
748	850
708	850
659	850
	860
	864
	869
	879

Obliquity - 0°
Projectile Type - Caliber .22T37 (17-grain) fragment-simulating. Hardness, Rockwell "C" 29-31.
Protection Ballistic Limit (V50) - 818 Ft/Sec.
Average Thickness of Liner, T54-1 - 0.092"
Minimum Thickness of Liner, T54-1 - 0.071"
Maximum Thickness of Liner, T54-1 - 0.113"

Ballistic Test Data of Nylon Liner, Helmet Steel T54-1

Striking Velocities Ft/Sec Resulting In	
Partial Penetrations	Complete Penetrations
733 Highest Partial	698)
728	698) Lowest Complete
703	713
688	718
664	718
610	718
595	737
	752
	742
	757
	757
	767
	806
	821
	840
	840
	934
	949
	1057

Obliquity - 0°
Projectile Type - Caliber .30 (44-grain) fragment-simulating. Hardness, Rockwell "C" 29-31.
Protection Ballistic Limit (V50) - 706 Ft/Sec.
Average Thickness of Liner, T54-1 - 0.093"
Minimum Thickness of Liner, T54-1 - 0.073"
Maximum Thickness of Liner, T54-1 - 0.119"

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